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Part I

# DYNAMIC EVALUATION OF EXPERIMENTAL INTEGRAL FUEL-TANK SEALANTS

Research Applications Division
Systems Research Laboratories, Inc.
2800 Indian Ripple Road
Dayton, Ohio 45440

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A research program has been instituted to investigate and evaluate experimental integral fuel-tank sealant materials under laboratory conditions which closely simulate those of actual aircraft integral fuel tanks during flight. As part of this effort, a unique facility has been designed and fabricated for the evaluation of a variety of joint configurations. The facility consists primarily of two separate biaxial stress machines in which temperature, pressure, and vibrational strain can be programmed for

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) automatic operation. Specimens can be strained longitudinally and torsionally to simulate actual flight conditions. Frequency and amplitude of the strains can be independently set and recorded. Simulated fuel-tank and environmental pressure can also be adjusted independently. Early difficulties with sealant-failure detection and with undesirable thermal strains have been largely resolved and preliminary evaluations of continuous-fillet specimens utilizing two sealant materials have been performed.

## FOREWORD

This report was prepared by Lee E. Isom of the Research Applications Division of Systems Research Laboratories, Inc., 2800 Indian Ripple Road, Dayton, OH 45440, under contract F33615-78-C-5098. The program was administered under the direction of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, OH, with Mr. William F. Anspach (AFML/MBT) as Project Engineer.

The equipment developed and evaluations described in this report were accomplished in the Research Applications Division Laboratory of SRL during the period 3 July 1978 through 3 July 1979.

The author would like to express his appreciation to Mrs. Marian M. Whitaker, Mr. Walter C. Tripp, and Mr. William F. Anspach for their editorial comments on the report. Finally, the author would like to acknowledge the technical contribution made by Mr. William F. Anspach, Dr. William R. Mallory, Mr. David W. Grooms, Mr. David P. Pedrick, Mr. William H. Knopp, and Mr. Charles M. Guston toward the completion of the Elastomer Test Facility.

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INTRODUCTION

Optimization of modern aircraft has led to the widespread use of integral fuel tankage. This concept makes use of existing internal cavities in the wings and other parts of the aircraft for fuel storage, the aircraft structure becoming the walls of the fuel tank. These cavities are rendered fuel tight by sealing potential leak paths such as seams, joints, and fasteners with elastomeric sealants. Different sealant configurations such as fillet, faying surface, and channel (groove injection) have been developed for this purpose. Also new sealant materials are continually being developed both to solve problems on existing aircraft and to meet the requirements of new high-performance aircraft, including long-life performance in the fuel-tank environment at temperatures ranging from -65°F to +600°F. Evaluation of sealant materials should include their exposure to the complex set of physical variables which occur in actual use since failure can result from interactions and synergistic effects of the various physical properties, e.g., adhesion, strength, and elongation, over the entire temperature range. This is particularly important since sealant materials frequently operate near their physical limits.

Evaluation of new sealant materials and sealing configurations can be enhanced through the use of bench-scale dynamic apparatus. Since real-time dynamic testing of full-scale parts is very expensive, preliminary screening by dynamic laboratory evaluation under conditions closely simulating those found in actual aircraft is very desirable. Also, experimental sealants may be available only in limited quantities; therefore, bench-scale evaluations are desirable because only a relatively small amount of sealant material is needed. The evaluation apparatus must be flexible to allow for a variety of sealed joint configurations and environmental conditions.

The objectives of the work described in this report were to develop a second apparatus for dynamically evaluating fuel-tank sealants under simulated flight conditions and to evaluate sealant samples supplied by the Air Force Materials Laboratory using this apparatus and evaluation parameters (temperatures, strain amplitudes, etc.) determined by AFML.

Under a previous Air Force Contract (F33615-76-C-5253), SRL developed a dynamic test apparatus which is capable of simulating flight conditions including loading, take-off, cruise and high-speed flight, landing, and shutdown. The system is capable of repeating this flight simulation and of terminating the evaluation when the sealant leaks at a preset level A second, improved system similar to the first has been constructed under the present contract. Suitable test specimens have been designed and, in the case of the continuous fillet and corner fillet, constructed.

# SECTION II

## DEVELOPMENT OF DYNAMIC EVALUATION EQUIPMENT

The purpose of this section is to summarize progress made during the past year on the integral-fuel-tank-sealant dynamic test capability. The test facility (Fig. 1) has undergone a major change with the addition of the second testing apparatus which incorporates the technical design changes which were found to be necessary or desirable from operation of the first machine. The two testers are identical in their operation but differ in design (Figs. 2 - 7). The first machine has a glass-globe upper chamber and a cam-driven motion mechanism, while the second machine has a metal upper chamber with viewports and an adjustable-offset drive mechanism.

### 1. SECOND EVALUATION UNIT

Improvements which were made to the first evaluation machine have been incorporated into the second. In addition, some features--which were difficult and/or expensive to include on the first machine because their desirability became evident only after the apparatus was constructed--have been built into the second machine.

The Pyrex chamber of the first machine provides somewhat less visibility than desired because the optical quality of the Pyrex is poor and also because it is desirable--for safety reasons--to place a punctured metal screen around it. Therefore, the second machine was designed with a stainless steel chamber, which has two viewing ports placed at appropriate locations. These ports allow viewing of any point in the chamber and allow access to the chamber with the specimen in place--a feature not available in the first machine.

In the second machine, torsion on the cup is measured by placing an LVDT push rod against a tab clamped directly onto the cup. This is a more direct method than the measurement of arbor motion which is presently being utilized. This new method should reduce the possibility of error due to slippage, although no such slippage has been observed.

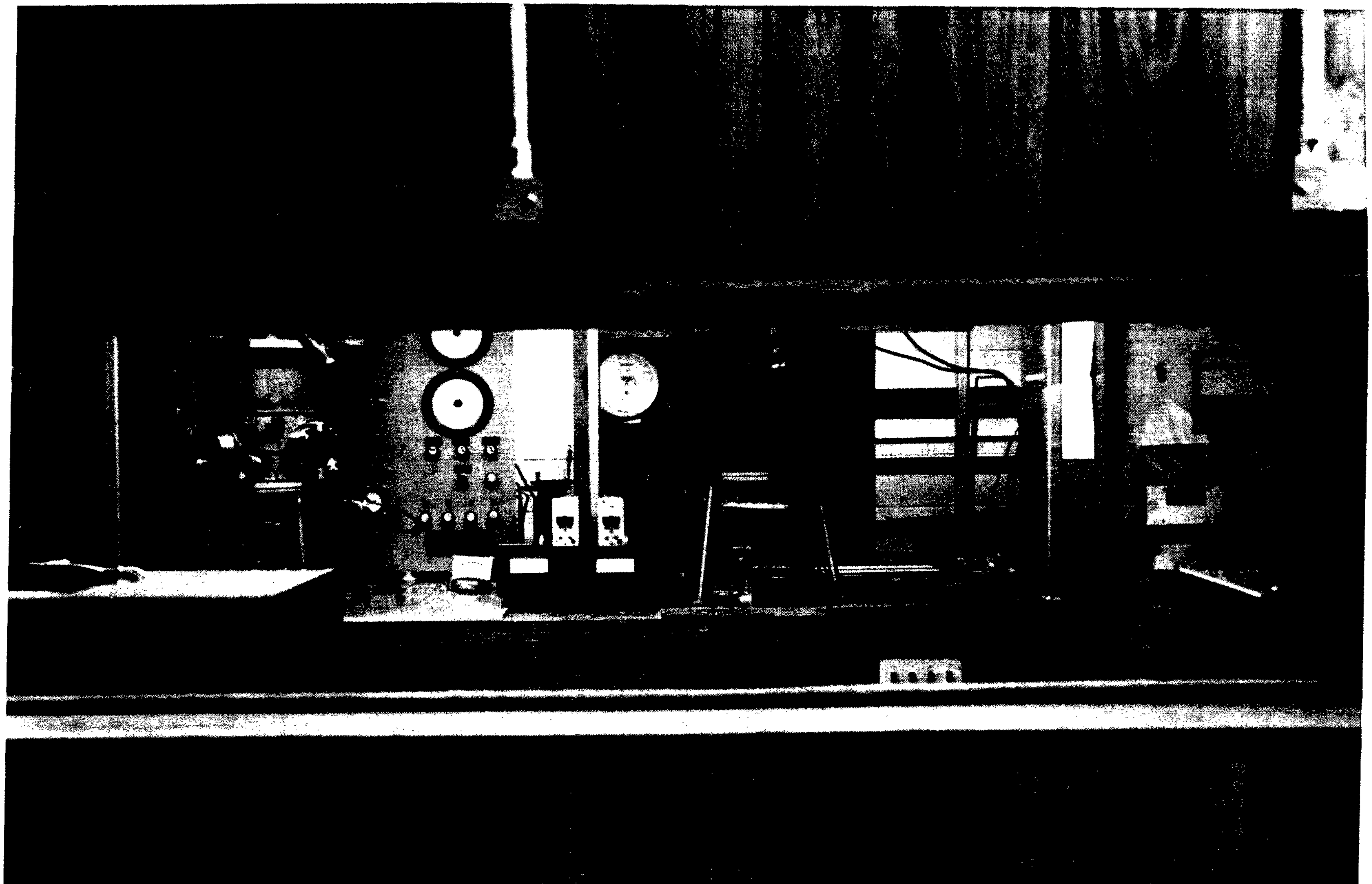

Figure 1. Elastomer-Sealent Test Facility

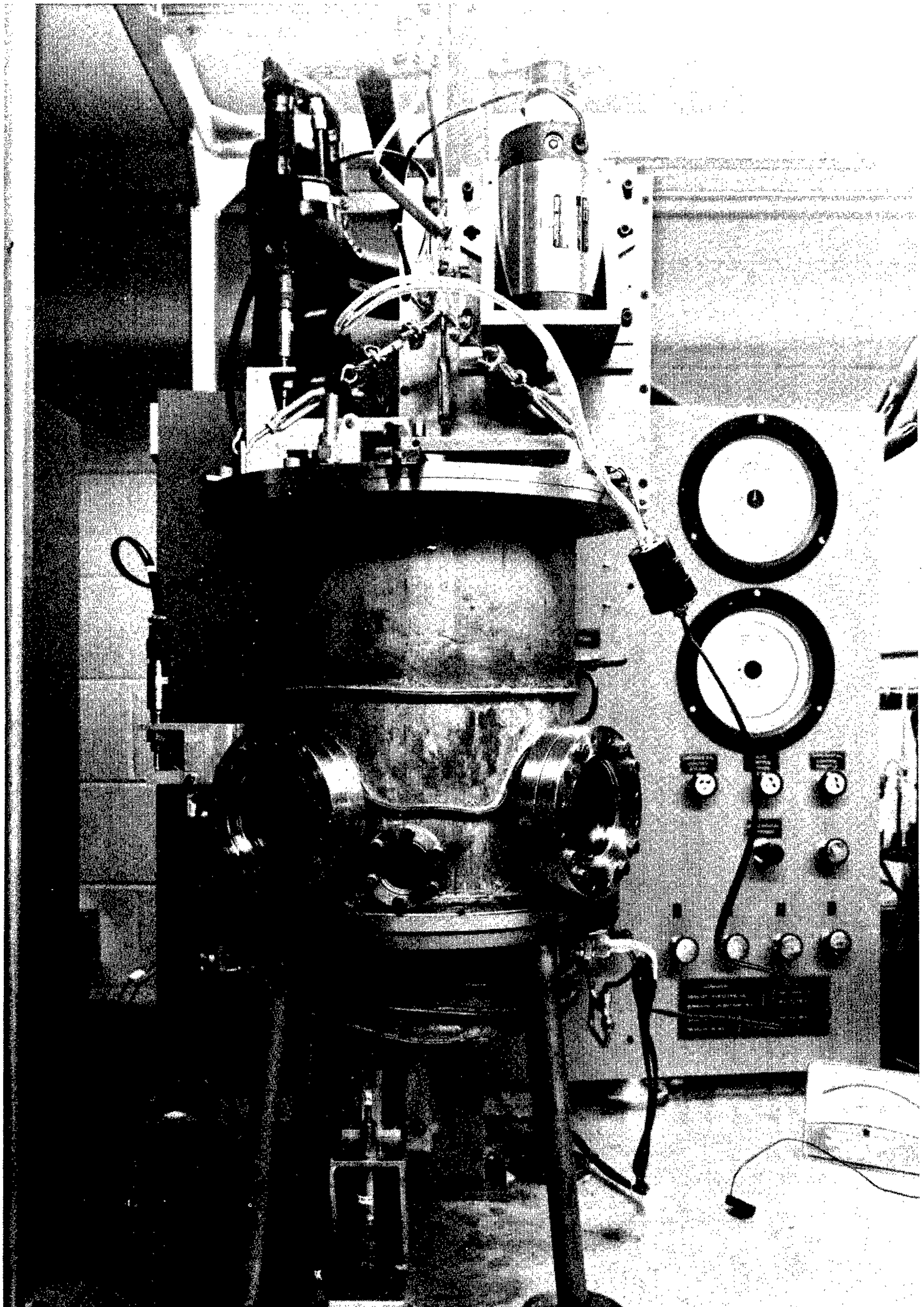

Figure 2. Second Evaluator

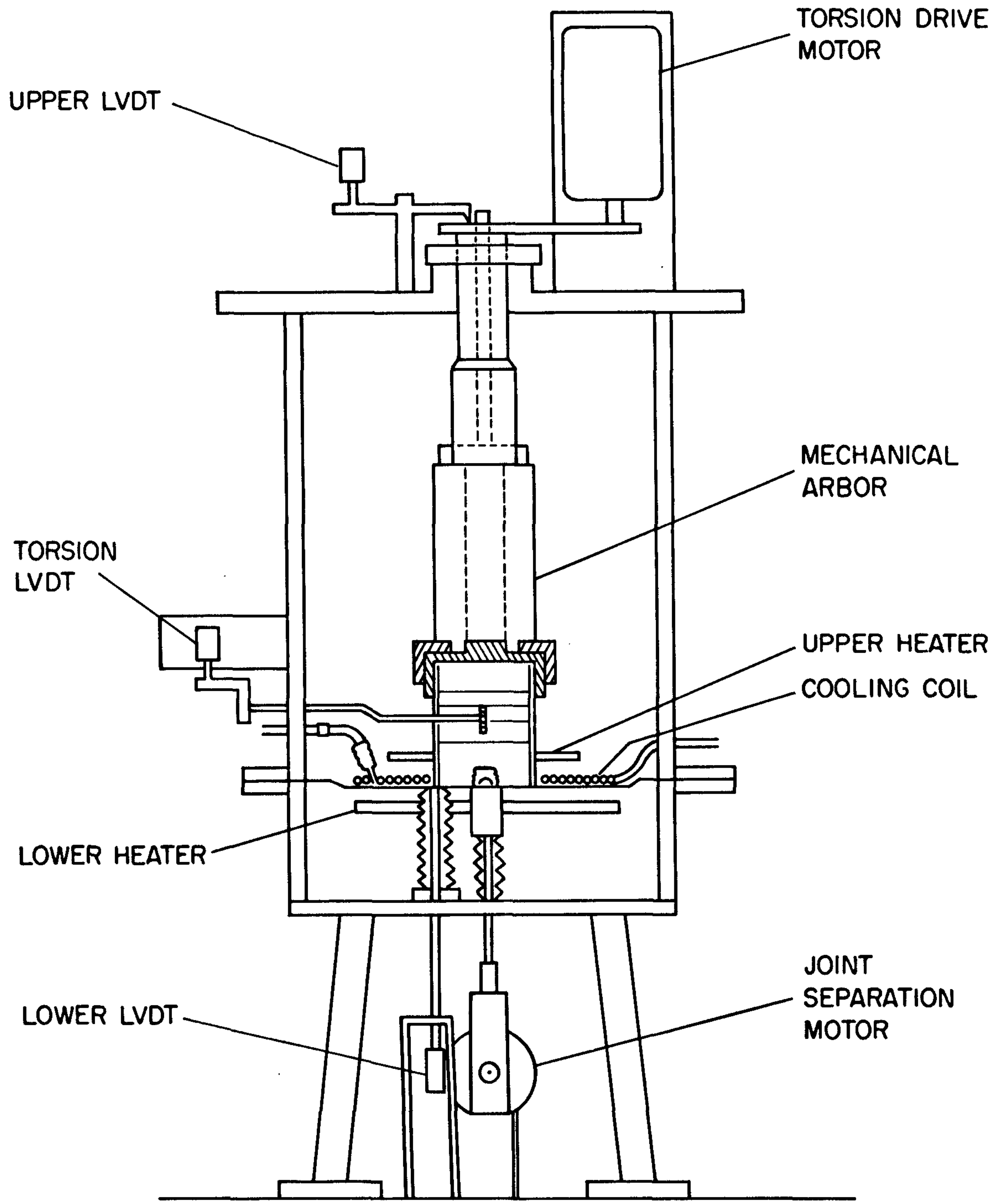


Figure 3. Cutaway Drawing of Internal Mechanism for the Second Evaluator

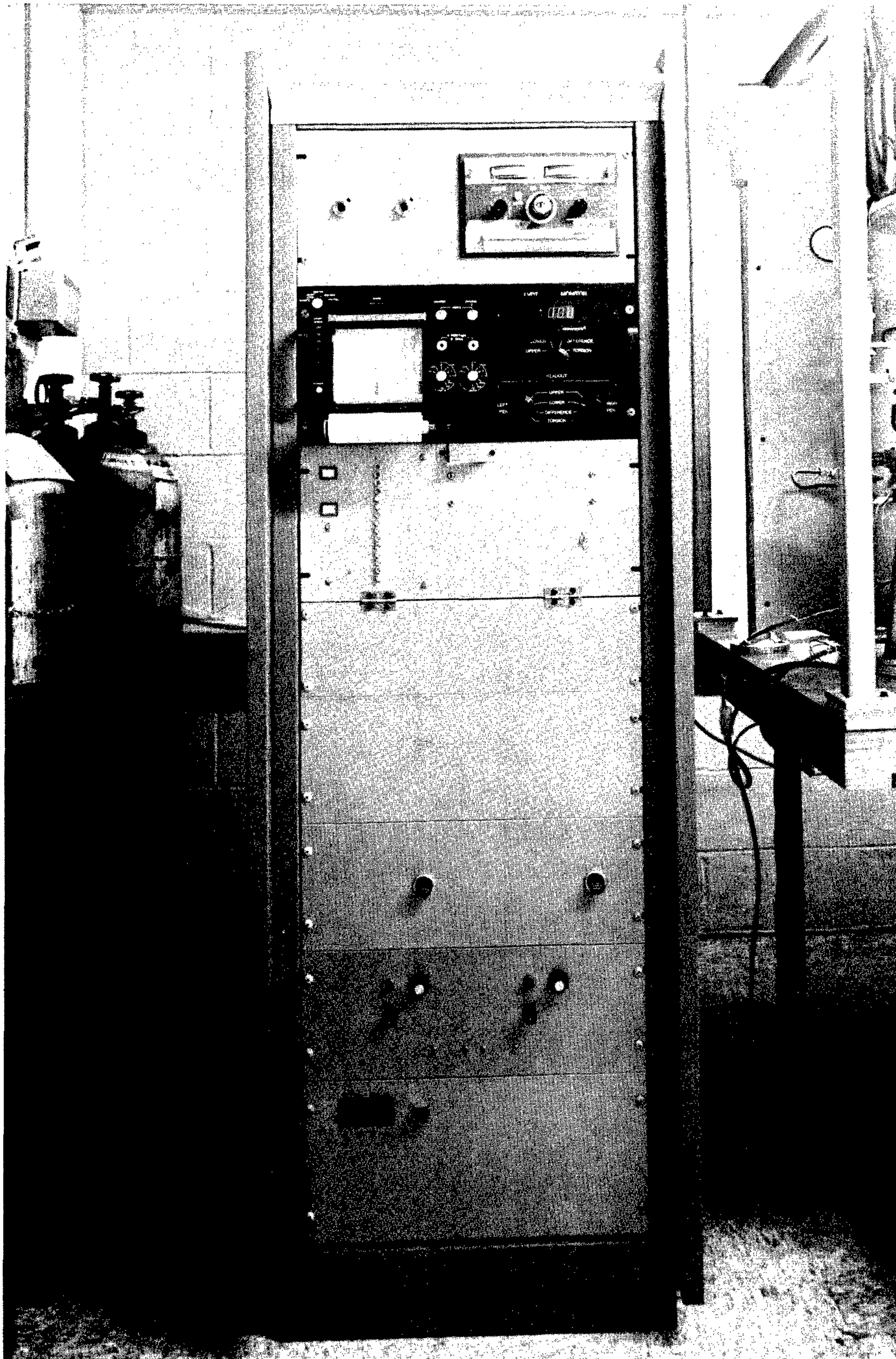

Figure 4. Console of the Second Evaluator

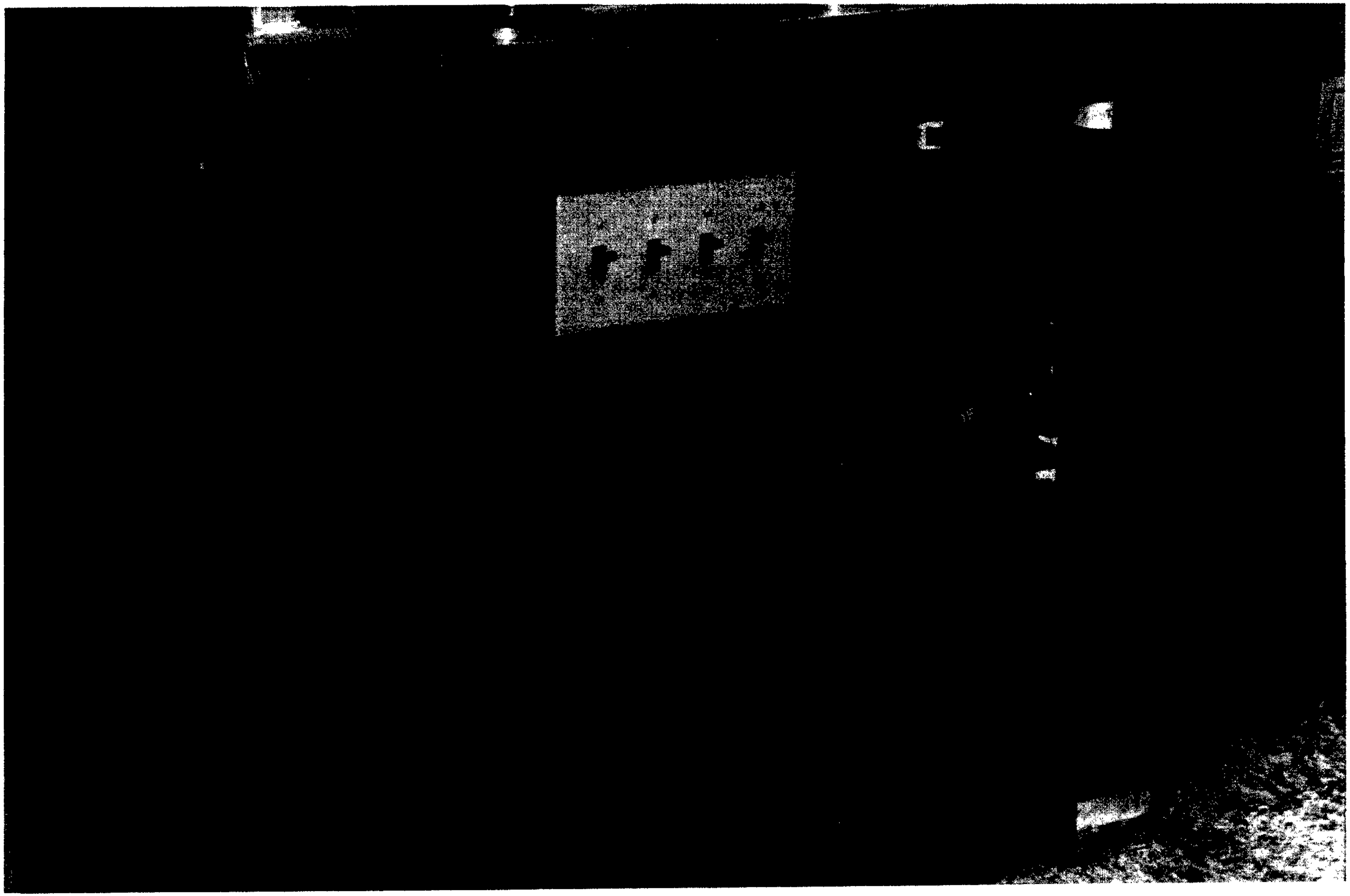

Figure 5. Vacuum Pumps of the Second Evaluator

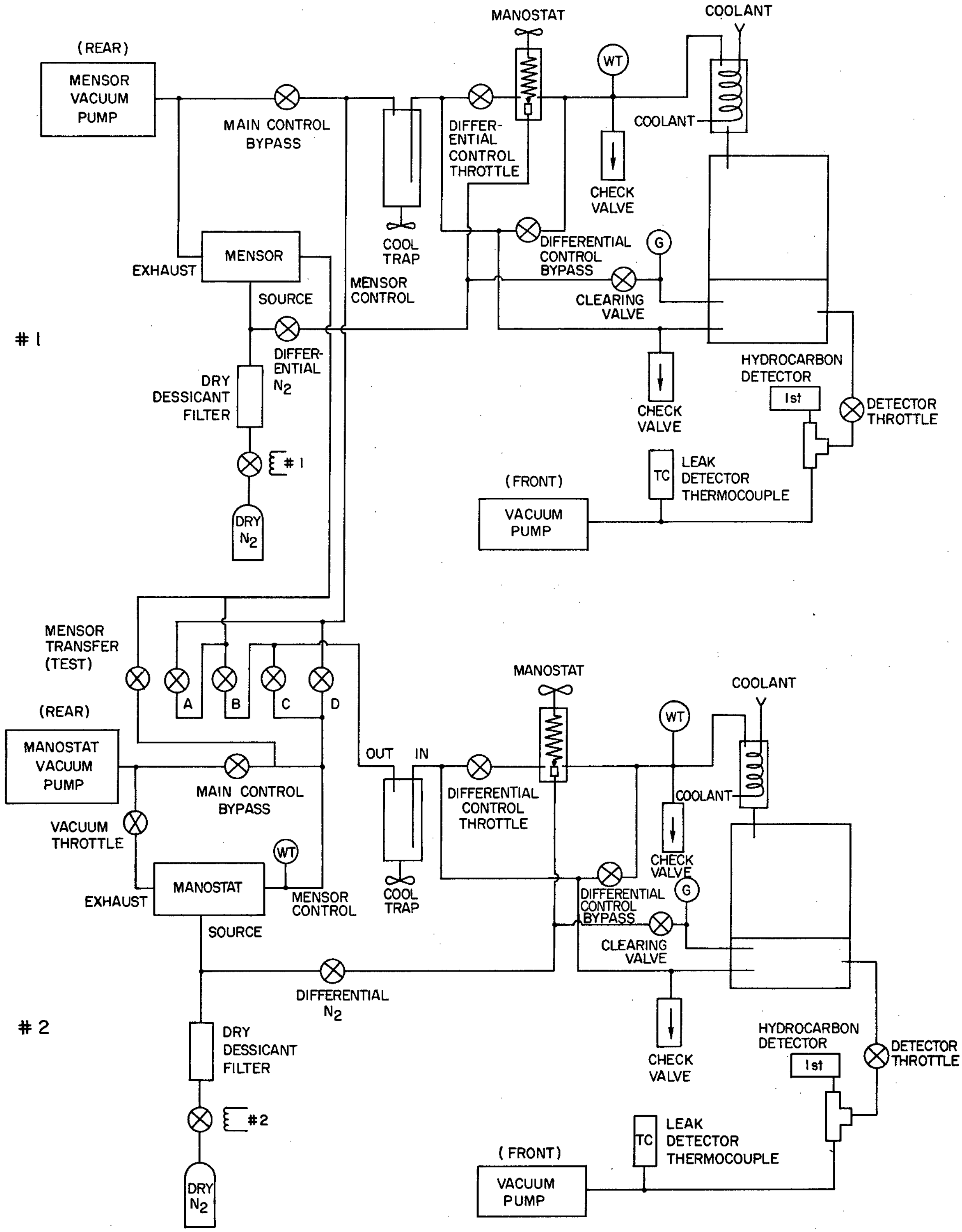


Figure 6. Flow Diagram of Complete Facility Vacuum System

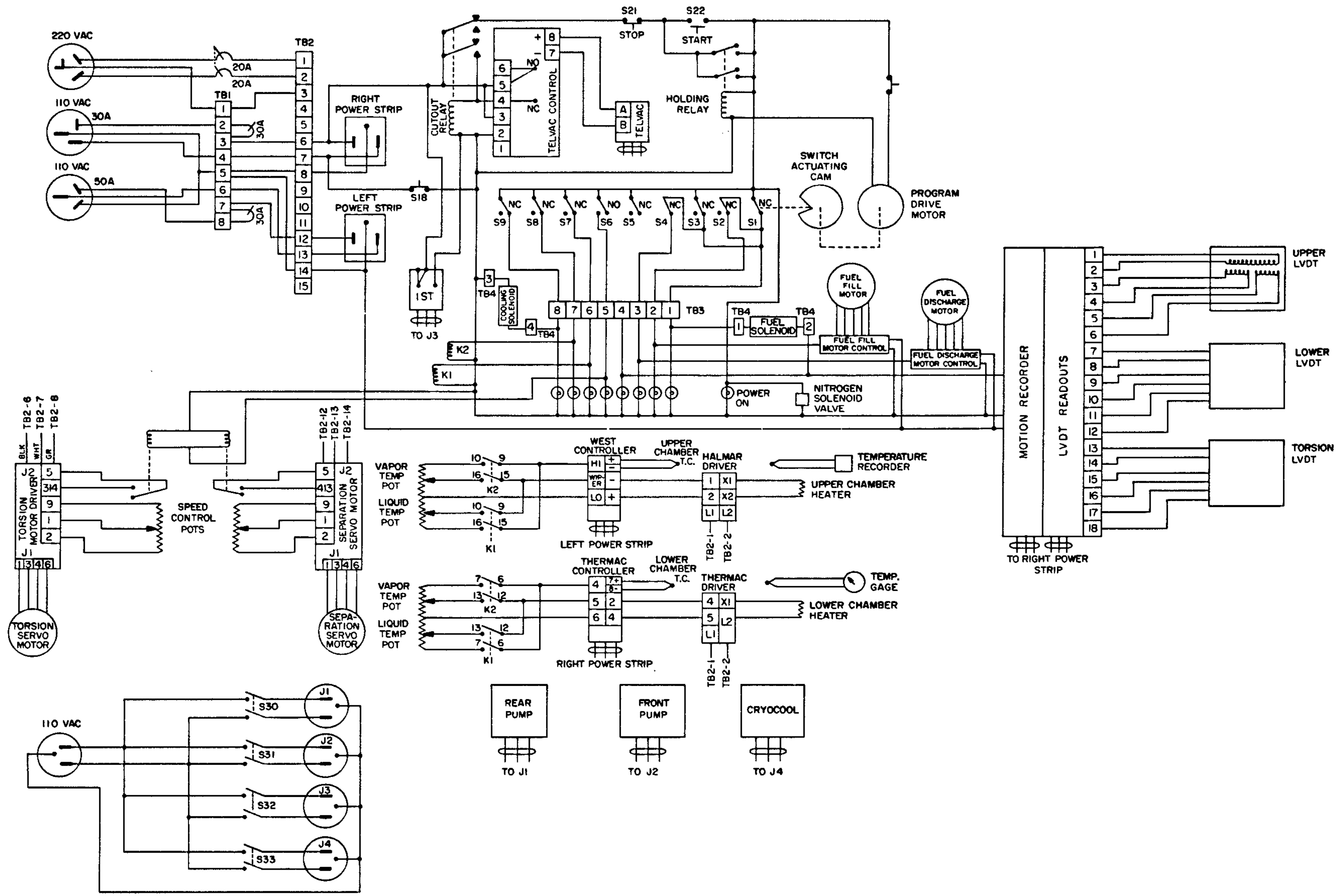


Figure 7. Electrical and AC Distribution Diagram

Adjustment of strains is accomplished by means of a machine boring head used as a continuously adjustable cam. This reduces the bulkiness of the strain drive assembly which is particularly desirable in the case of the torsional drive. The torsion motor on the first machine must be moved a considerable distance off the chamber axis to apply the required range of torsional strains. This causes alignment difficulties.

Since the Wallace-Tiernan Aneroid Manostat functioned so well as a differential controller in the first machine, two Manostats are being used in the second machine--one for the control of pressure in the lower chamber and one for the differential controller for the upper chamber.

The Mensor quartz manometer controller presently in use on the first machine as a lower-chamber pressure controller and a Manostat have been connected in such a way that either can be used with either machine (making the Mensor available for vacuum diagnostics). The reason for using a Manostat in place of a Mensor in the second machine is that the Mensor is much more expensive than the Manostat.

In the second machine a smaller bellows is used in the measurement of disc deflection. This reduces the force placed on the disc by the differential between the pressure in the lower chamber (3-5 psi) and ambient pressure (The inside of the bellows is open to atmospheric pressure.) This pressure differential creates an azimuthally asymmetric force on the disc and causes some uncertainty in deflection measurements. If the bellows in the first machine fails, it will be replaced with a smaller one.

Cooling coils on the new machine are silver-soldered directly to the chamber walls, making them more effective because of better thermal contact.

Design of the second machine was delayed until all major difficulties with the first machine had been resolved. It seemed unwise to design the same shortcomings into the second machine. Except for the modifications noted earlier in this section, the second evaluator is similar to the first.

## 2. ACCOMPLISHMENT OF DESIGN CHANGES

The following design changes were considered to be necessary and were implemented on the dynamic test facility after both machines were made operational.

### a. Specimen Cup Seal

A design change was required to prevent leakage past the cup seal which caused a premature automatic shut-down of the system. The design of the cup seal required the tightening of two metal discs against an "O" ring, causing the "O" ring to expand against the inside wall of the specimen cup to form a seal. Fuel leakage past the seal occurred when the cup was heated to the required operating temperature. The cup would expand at a faster rate than the seal discs, causing the seal to lose its grip against the inside wall of the cup. The problem was solved by purchasing titanium, aluminum, and stainless plumbing fittings, cutting them to form, and welding them inside their respective cups. This method of sealing the cups has now proven to be successful in both machines.

### b. Recorder Modification

A strain-recorder modification was made to lower the chart speeds to 1 mm/min. minimum on the first evaluation. The first machine can now operate continuously for the duration of a test without use of an excessive amount of chart paper.

### c. Corner-Seal Configuration

The corner-seal configuration as shown in Fig. 12, p. 23, of AFML-TR-77-152, Part II, dated Nov. 1978 was deemed inadequate for testing. A new design was submitted and accepted, and the configuration was fabricated (see Fig. 9). The specimen has not been tested, because fabrication was just recently completed and the specimen delivered for application of the sealant. Two corner-seal specimens were fabricated.

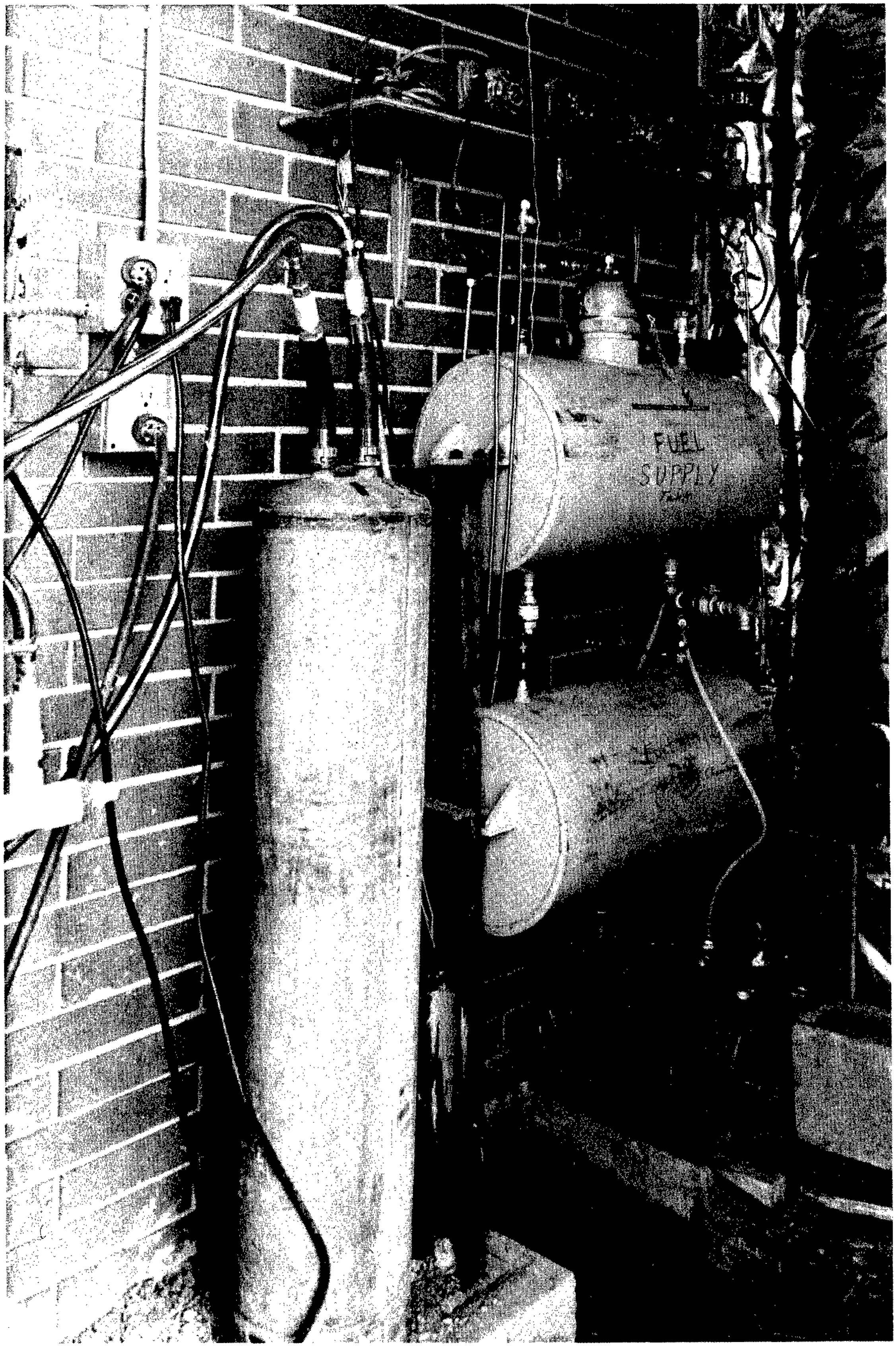


Figure 8. Fuel Supply and Holding Tanks

d. Channel (Groove-Injection) Configuration

A test-specimen design has not yet been approved for fabrication, although two rough drafts of proposed designs have been completed. The channel-sealant test-specimen designs have been delayed by difficulties encountered in defining representative strains for a channel-sealed joint and by constraints placed upon the specimen dimensions by the joint-deflection requirements. Strain data have been obtained with the help of Mr. J. W. Mahoney, Rockwell International Corp., which will allow finalization of the design and fabrication of these test specimens in the near future.

e. Limited Automatic Operation

The original program controller required manual resetting of the program card after each 24-hr period of operation. A continuous-cycle timer has been purchased and installed for each machine which will allow independent operation for an indefinite period of time. Continuous unmanned operation is now possible for more than 72 hr (required for operation over weekends) and is now limited mainly by the volume of dry nitrogen and fuel reserve (Fig. 8). Neither the dry nitrogen nor the fuel supply should be permitted to become completely exhausted because the absence of either will cause a change in test conditions. If the dry-nitrogen supply becomes exhausted, the pressure differential will be lost and the system will pump to a full vacuum. If the fuel supply should become depleted, air could be brought into the heated chamber during the fuel-fill cycle or the fuel vapor might not be of sufficient concentration to indicate specimen failure.

f. Cooling System

A method of cooling the sample and chamber which employs water circulated through a closed-loop cooling system rather than the use of liquid nitrogen is now being employed. The use of liquid nitrogen for routine cooling was discontinued due to limited availability and expense. The closed-loop cooling system is capable of supplying cooling water chilled to 55°F (12.78°C) on a cyclic basis. This permanently installed building cooling system has proven to be more than adequate for cooling the sealant tester from a high-heat setting to room temperature within the required time limits. Liquid nitrogen will still be required for tests at -65°F (-53.89°C); however, the number of tests will be limited and the additional expense is justified in this instance.

g. Cold-Trap Cooling

A Cryo-Cool unit was purchased to eliminate the need for liquid nitrogen in the vapor trap of the tester. The unit cools a Dewar of denatured alcohol to a temperature of -43°F (-41.67°C), while a flying-vane pump circulates the alcohol through coils built into the cold trap of each system. It is not known whether the capacity of the present Cryo-Cool unit will permit effective cooling of both cold traps simultaneously, because the machines have not yet been operated in a routine manner simultaneously.

h. Temperature Fluctuation

An attempt was made to use a single thermocouple as a sensor for both the temperature recorder and the temperature controller. It was noted that an interaction existed between units, causing an erroneous temperature indication when both units were connected to a single thermocouple. The recorder-temperature print pen would fluctuate and move to another setting whenever the temperature controller changed its error indication. Likewise, when the temperature recorder changed channels, the error indication on the temperature controller would fluctuate and move to another point. Interaction between the two units was eliminated by using two thermocouples attached to the same point on the disc--one thermocouple for each unit.

i. Heating of Test Specimen

After two tests had been conducted with a polyester sealant, 3M EC-2288, it became apparent that the temperature of the sealant bead on top of the disc was lower than the temperature being measured at the bottom of the disc by the thermocouples. This was concluded after inspection of the sealant specimen revealed no significant thermal degradation after 78 cycles with a vapor temperature of 525°F (274°C). Another thermocouple was placed on the top of the disc, near the sealant bead; it was noted that when the thermocouples on the bottom of the disc monitored and controlled the temperature at 525°F (274°C), the sealant temperature never exceeded 300°F (149°C). Stopping the flow of cooling water through the chamber jacket provided some improvement. Moving the control thermocouple to the top chamber provided the desired temperature at the sealant bead; however, temperatures above 700°F (371°C) were being recorded on the bottom of the disc. It then became apparent that two separate controllers would be required--one to control the temperature of the upper heater and one to control the temperature of the lower heater.

An experiment using the temperature controller and driver from the second system was conducted to determine whether this was a viable solution. The results of the experiment proved that it was possible to obtain the desired temperature on both sides of the disc simultaneously when two separate temperature-control systems were used. Thus, a separate temperature-control system was installed in each machine. Recent tests indicate that the new temperature controllers will provide the temperatures required; however, as of this writing, neither unit has been operated for a sufficiently long period of time to allow adjustments to be made for achieving optimum stability in the recorded print-out.

## SECTION III
## EVALUATIONS

An Elastomer Laboratory has been created by the Research Applications Division at SRL's Research Campus on Indian Ripple Road in Dayton, OH, expressly for the purpose of conducting elastomeric-sealant evaluations. Fuel-storage and waste-fuel tanks are mounted in a protected external enclosure attached to the laboratory wall. All flexible tubing used in pumping the fuel as well as the fuel pumps themselves are housed in this enclosure. An automatic fire-protection system using ultraviolet flame detectors and Halon 1301--a personnel-safe fire suppressant--has been installed in the laboratory. This system has auxiliary battery power in case of power failure. It is monitored 24 hours a day by ADT Security Systems.

A test-specimen configuration for evaluation of continuous-fillet seals was designed under the previous contract and has been used for all evaluations to date. This continuous-fillet cup and disc specimen was shown in Fig. 6 of AFML-TR-77-152, Part II. It is anticipated that the disc used for continuous-fillet evaluations will be used for most other evaluations. A preliminary design for corner-seal evaluations is shown in Fig. 9. The upper part of this cup will fit the arbor, and the lower part will simulate the corner configuration. The corners were constructed separately and then welded together. For titanium specimens the top part can be hot-spun if suitable titanium tubing is not available (it was not available at the time the cups for the continuous fillet were made). Aluminum samples were made from sheet aluminum (bottom) and aluminum tubing (top) welded together.

Evaluations are being conducted on several sealants selected by the AFML Project Engineer. The material chosen for evaluations for initial equipment checkout was Dow Corning 77-028 fluorosilicone sealant. Due to limited availability of this material and an extended check-out phase of the evaluator, the evaluations were switched to Dow Corning 77-108 (FCS 210)--a hybrid fluorosilicone/fluorocarbon--and then to a 3M Co.

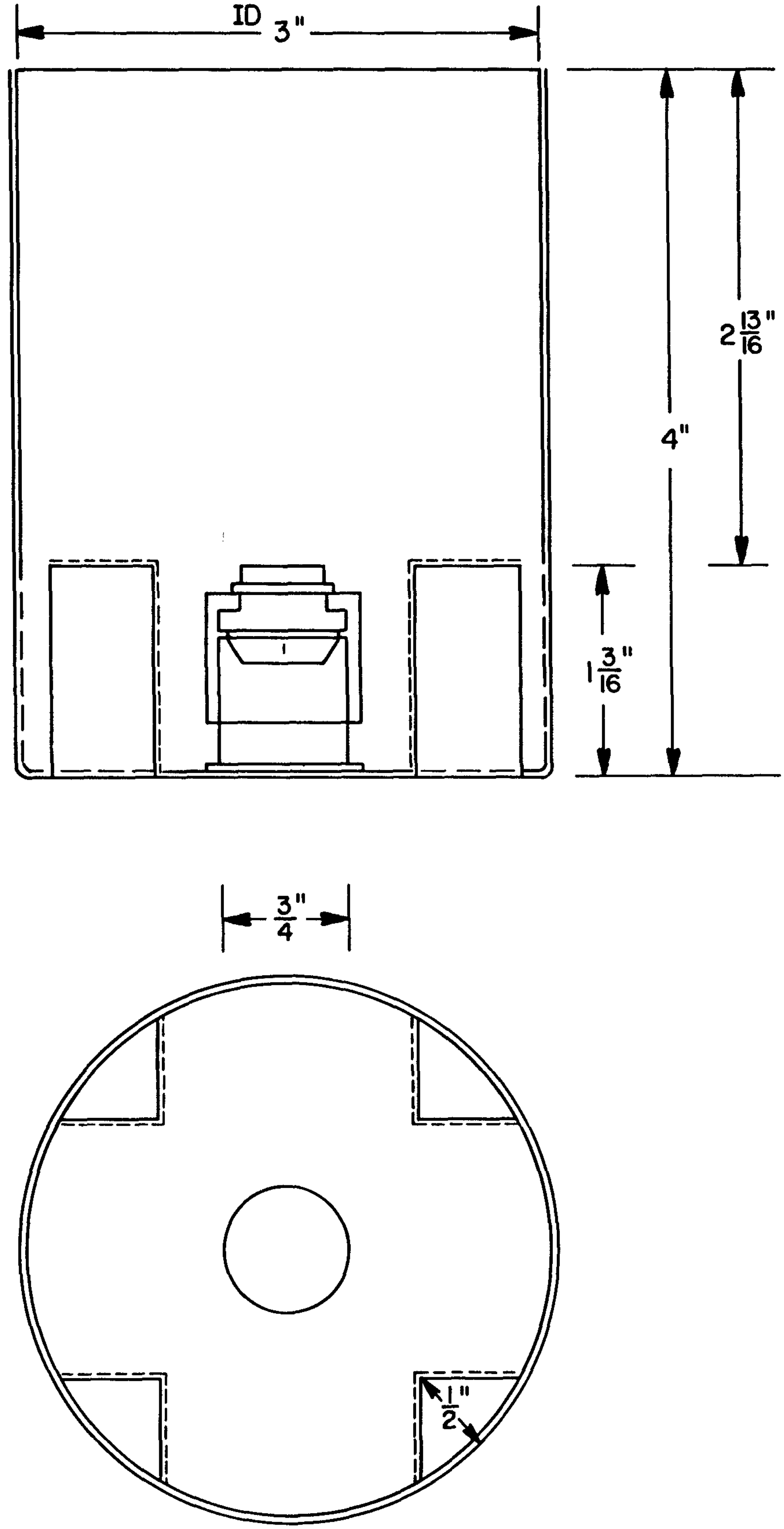


Figure 9. Corner-Configuration Test Specimen

polyester sealant, EC-2288. The latter material has a shorter life at high temperatures than the FCS 210 and, hence, speeded up verification of evaluator performance at high temperatures. Also, since data are available on this material from other sources, a correlation with actual flight data can be made. The sealants are being evaluated under a variety of conditions (e.g., fuel vapor over the 450-550°F temperature range). Each data point represents evaluation of several samples of the same material under identical conditions. A complete evaluation of an elastomeric sealant will consist of several data points. The immediate goal is to provide sufficient characterization of the polyester sealant to permit correlation with more expensive flight-test data in order that the more economical laboratory method may be used in evaluating presently available sealants and those now under development.

Figure 10 is a reproduction of a typical high-temperature thermal cycle as it is printed on the temperature recorder. It shows the overlapping of two thermal curves, the one for the first machine beginning at point (A) and ending at point (G). The second machine was activated about 50 min. later, and its printed thermal cycle overlaps that of the first. Before a test is initiated, the lower chamber is thoroughly cleaned of hydrocarbons, oil, fuel, etc., and a specimen (sealant sample) installed between the upper and lower chambers. The chambers are then bolted together and sealed. The proper valves are set and the vacuum pumps activated to evaculate the chamber. When the desired vacuum of 0.270 mm Hg or lower is reached, the chambers are back-filled with dry nitrogen to a pressure of about one-third atmosphere. Then a pressure differential is set between the upper and lower chambers, with the lower chamber being set to ~ 1 psi less pressure than the upper chamber. The start button is then pressed to start the continuous-cycle timer which causes the following sequence of events to be repeated automatically until the sealant specimen fails and vapors enter the lower chamber.

The proper level of fuel has already been pumped into the upper chamber when Point (A) of Fig. 10 is reached. Point (A) is the start of the liquid temperature phase. Point (B) is the liquid-temperature regulating

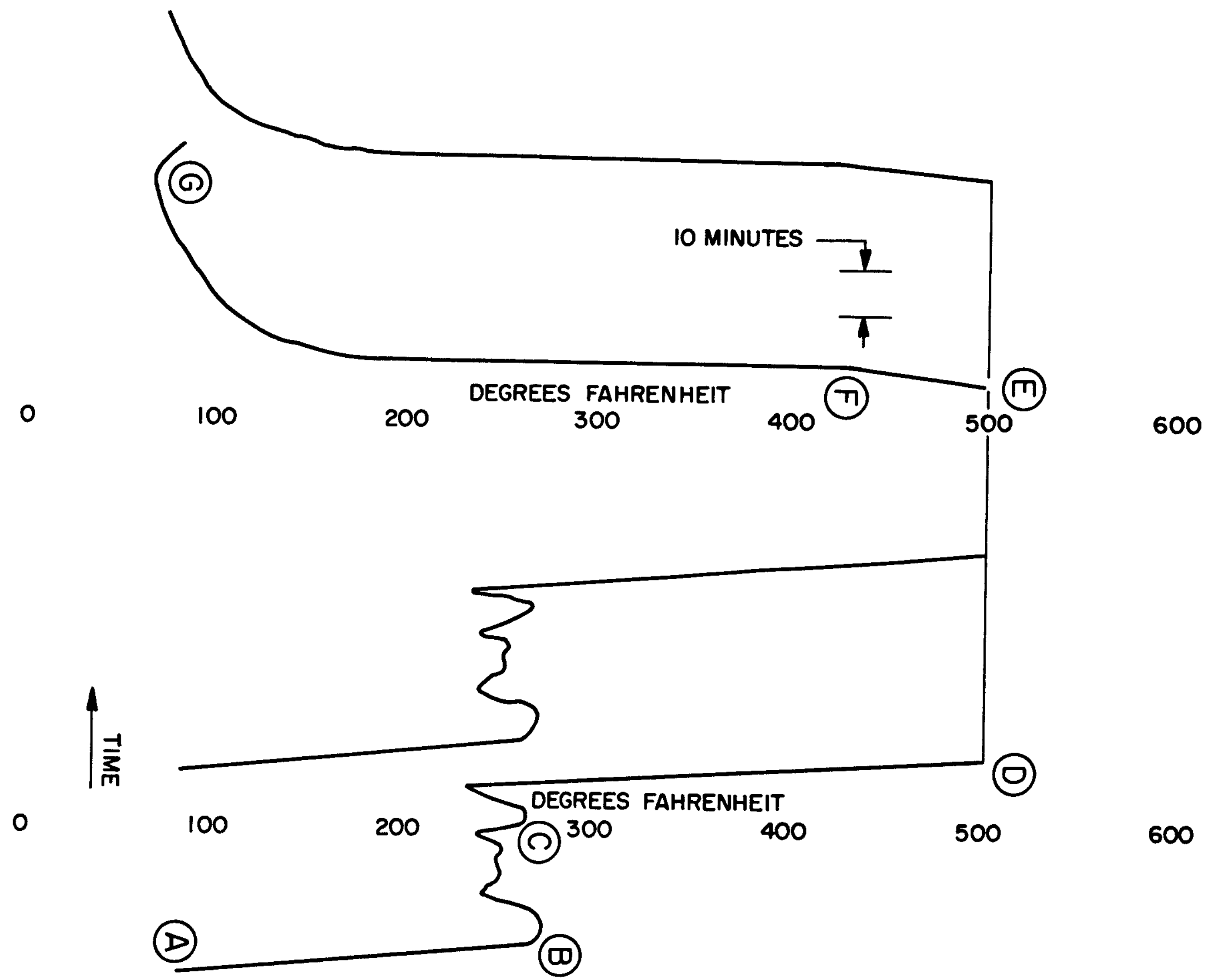


Figure 10. Thermal Cycle for Sealant Evaluation

point. At Point (C) the fuel is extracted from the chamber by means of a fuel discharge pump assisted by a vacuum pump which maintains vacuum in the used-fuel holding tank. The timer then initiates the vapor-temperature phase in which the specimen temperature is raised to the test temperature (D) where it remains for approximately 90 min. (E). From Points (A) through (G), mechanical strain is being applied to the specimen through mechanical attachments driven by two variable-speed drive motors--one for joint separation and the other for applying torsional strain. At Point (E), heat is turned off and cooling water is circulated through a copper cooling coil that surrounds the specimen. Point (F) is actually the start of the fuel-fill phase for the next thermal cycle. Fuel is pumped in at Point (F) to assist in specimen cooling. At Point (G) the cooling water is shut off and shortly thereafter this cycle is repeated until the specimen becomes deteriorated and leaks, allowing fuel vapor to enter the lower chamber. An electronic hydrocarbon dectector senses the presence of fuel (hydrocarbon) and energizes a cutoff relay that removes electrical power from the system and stops the timer.

After the chamber is allowed to cool for about one-half hour, it is opened and the specimen removed. The point of failure is then recorded and plotted on a temperature-vs-cycles to failure graph. A separate graph for each type of material tested will be made.

## SECTION IV

## RESULTS

During this reporting period, approximately thirty (30) test specimens have been subjected to a composite total of 433 high-performance flight cycles in the dynamic test apparatus. This is equivalent to approximately 628 flying hours at high temperature in fuel vapor (high speed, fuel tanks empty) and approximately 216 flying hours at intermediate temperature in liquid fuel (high speed, fuel tanks full). The above data are the result of a variety of tests conducted for a number of different purposes; and although these data represent a significant accomplishment, they are reported more as an indication of the work performed and experience gained in the operation of the equipment than as an indication of successful materials evaluation. As one might expect with a relatively new and sophisticated materials-evaluation system, some of the evaluations produced questionable data points and others were required for solving problems and verifying the effects of modifications to the equipment and procedures.

A major objective of the evaluation conducted during this reporting period was to complete the characterization of the 3M polyester sealant, EC-2288, which was initiated under the previous contract (F33615-76-C-5253) making use of the first test unit. After several tests had been conducted with all the subsystems operating without an obvious malfunction for the duration of the test, it became apparent that the sealant material was not reaching the temperatures indicated by the thermocouples which were located on the bottom of the disc directly below the sealant bead. This was concluded after inspection of a sealant specimen that revealed no significant thermal degradation after 78 cycles with a vapor temperature of 525°F (274°C). Placing a thermocouple on top of the disc near the sealant bead verified the above conclusion. Ultimately the problem was solved by using separate controllers and control thermocouples for the top and bottom heaters (see Section II2i, pp. 15 - 16). Since the installation of the second heat controller, two test specimens evaluated at fuel vapor temperatures of 525°F (274°C) and 500°F (250°C) have failed after

5 and 6 flight cycles, respectively. These failure points fall directly on a predicted failure curve (flight cycles to failure versus fuel vapor temperature) for the EC-2288 sealant which correlates directly to flight test data from aircraft flying the flight cycles being simulated in this evaluation. Characterization of the EC-2288 sealant will now be completed, which will include repeating the tests previously conducted.

There is currently a clear lack of credible data considering the number of tests conducted. This situation is the result of subsystem failures, i.e. failure of leak detector, arbor, and arbor seals; fatigue cracks in specimen discs; heat-controller problems, etc. The variety of problems encountered made it difficult to identify the generic heating problem discussed above, resulting in further delays. Fortunately much has been learned from these problems, and most have been corrected via modifications to the equipment and/or procedures. The result is that fewer subsystem and support equipment malfunctions have been experienced during recent tests, and the prospects for obtaining credible data in the future are good.

## SECTION V

## CONCLUSION

The Air Force has a critical need for rapid, economical, and realistic evaluation of sealant materials. To provide an economical facility for dynamically evaluating these sealants, a unique system has been constructed which subjects the sealant material in the laboratory to mechanical forces, pressures, temperatures, and fuel-exposure conditions closely simulating those experienced in aircraft integral fuel tanks during flight. The system can simulate a complete flight profile including fuel loading, take-off, cruise and high-speed flight, landing, and shut-down. The system is capable of repeating these simulated flight conditions until the sealant material fails. A vapor leak into the lower chamber of the tester automatically terminates the test. The equipment allows automatic evaluation of elastomeric sealants using a variety of joint configurations.

Two machines are now operational and at the same stage of development, except as noted in the Introduction. Since the submission of AFML-TR-77-152, Part II (dated Nov. 1978), a major effort has been directed toward the completion of the second system and upgrading of both systems. Tests are now being conducted with both systems and failure points are being recorded.



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